Student questions: Darlene Lim colloquium on "Designing and Developing for Human Scientific Exploration of the Moon, Deep Space, and Mars"

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What instrumentation was used to identify the volcanology on Mars and its similarity to that of the field location on Earth?

Much like a mission to Mars will go through a landing site vetting and selection process, the development of our research program included in-depth science discussions about where to conduct our analog research studies. Our science team looked through the literature and drew from their own experience to identify regions on Earth that would address the specific research questions that they were interested in studying. They were also tasked with downselecting to regions that would be logistically and financially feasible for our team to visit safely and economically. Scott Hughes and Shannon Kobs Nawotniak championed the choice of Craters of the Moon National Monument and Preserve in Idaho, while Steve Squyres put forward the Kilauea region of Hawaii Volcano National Park on the Big Island; these two regions became our field sites for the BASALT research program as they met the research and safety requirements of our team.

I could have possibly missed it but what are examples that could be unexpected in testing if we do not know what to expect?

I am not 100% sure that I understand this question, but I think that this is about my comment around the fact that when we go into the field we will always find the unexpected. This is because being in an uncontrolled setting means that problems that were not anticipated will pop up. This is the case whether one is operating on land, on water, underwater or in space. As such, conducting analog field activities is an excellent way to test whether certain capabilities and operational concepts will hold up under dynamic conditions.

If there is no way to remake the same environment, what specially are you trying to mimic since there is so much to take into consideration.

We use test conditions that are repeatable and constrained adequately in order to ensure that we can extract meaningful learning and conclusions from each excursion. Please see Beaton et al. 2019a and Beaton et al. 2019b for more information about our test conditions.

How do you balance directing an EVA team with letting them make their own decisions in the field?

Fundamentally, it comes down to ensuring that all team members – whether part of the Mission Support Center or the EV/IV crew – understand the goals and priorities of each EVA. This may seem very simplistic, but imbuing an entire, multi-disciplinary team with a clear and holisticunderstanding of the tactical and strategic mission goals that need to be met during each EVA and throughout the field mission is not simple. If you want a deep dive on all of the systems, capabilities, protocols and requirements that were implemented during our field missions to enable EV/IV crew autonomy and to enable meaningful bi-directional scientific exchange between the Mission Support Center and Mars over communication latencies, please refer to the collection of papers in our Astrobiology Special Issue https://www.liebertpub.com/toc/ast/19/3

What are some of the major challenges with organizing decision making in a large team, like a support team on Earth trying to direct one person on an EVA?
Ensuring that the team communicates clearly and effectively with each other from the get-go. Words mean different things to different people from various disciplines. Alignment between disciplines is really important to establish early on, and this starts with ensuring that everyone understands what each person is trying to communicate.

Are there student opportunities to get involved in analog work in the BASALT, SUBSEA, or other projects?
Yes, in fact there have been students from SESE on almost every analog project that I have been involved with. Typically, we get graduate students and post-doctoral fellows conducting the core research, while undergraduate interns will fill in other research and field support roles.

Did you simulate any "emergency" decision-making scenarios where the communication latency could make a major difference in the process?
No, this was not a goal of our research program. There are other analog programs that examine emergency scenarios.

What skills exactly do you use VR/AR to train for, and are there any applications for these technologies that are of use in normal, earth-based geology?
We used VR/AR to prepare for EVAs before they occurred and to support EVAs while they were underway. We have a paper that is under review with PSS that delves into the details of our VR/AR applications – look for Beaton et al. 2020 in the next few months.

And yes, the VR/AR methods we used can also be applied to terrestrial geology.

In your simulations, did you have the people in the field wear anything besides the backpacks containing the communications equipment to simulate the decrease in mobility and range of motions from wearing a space suit?
No - we are conducting complementary testing in spacesuits in simulated reduced gravity environments at Johnson Space Center to understand how the results and recommendations of BASALT (conops, tools, time to perform tasks, etc) are affected by reduced mobility, dexterity, field of view, etc

What is the biggest issue that needs to be resolved in order to have near instant communication back to Earth?

The problem is the speed of light, so there isn't really a technological solution. Depending on the relative positions of Earth and Mars in their orbits, they could be anywhere from ~4-22 light minutes apart. We don't foresee technology that would enable near-instant communication between the two planets.

Are there any Mars analog sites that you would consider more closely matching Martian conditions, but did not choose because of their accessibility?

Clearly, no one location on Earth is a perfect analog. The key thing when picking an analog site is to consider what your specific study questions are. For instance, there are basalts in Iceland with higher iron concentrations, closer to Martian basalts, but logistics considerations excluded them for consideration from BASALT because the iron was less important than the variety of water-rock interactions. Ideally, we'd get to work on high-iron, mafic lavas isolated far from more evolved rocks/dust and in minimal contact with humans or other animals. Geographic isolation has an unfortunate consequence of greatly increasing costs and logistical complexity. We always have to consider the scientific and logistical aspects in balance with one another.

Did the decision to change the "mission control" to "mission support center" have anything to do with the psychological aspect of being controlled from so far away, and the increasing independence expected of planetary exploration crews?

Absolutely. In past and current spaceflight, tasks and timing are carefully scripted by teams on the ground. As we explore further from Earth and encounter longer communication latencies, it becomes critical to acknowledge the shift from "control" to "support" that we'll have on the ground. We cannot ask a team of astronauts, regardless of how talented they are, to carry the weight of global scientific interests on Mars on their own, but neither should we treat them like programmable rovers. Over the course of our simulations, we repeatedly found that we had lesser outcomes when the Mission Support Center tried to think too far ahead of the field astronauts and treated them more like robotic assets than intelligent and thoughtful scientists/explorers.

Due to the fact that us humans are kind of fragile creatures, would you agree that sending robotics on these missions would be more beneficial then trying to send humans?

There are definitely people who have that view, but I disagree with them. Consider how long it took for the Spirit rover to complete a marathon (26.2 miles) on Mars: over 11 years. The rover teams do absolutely brilliant work, but they are effectively forced to operate via a remotely-control vehicle being controlled through a significant time delay. How much more quickly could we have achieved the same coverage, plus the added scientific insights from human observation, had we had a team of astronauts driving around in a rover? Human problem solving and innovation are still very valuable. Our analog projects envision a future where exploration is carried out by human and robotic endeavors working together.

How much power does it take to broadcast the low speed 0.5Mb/s upload signal from Mars to Earth?
This question is a bit unclear. Are you asking for a link budget between Earth and Mars (RF power)? There are too many variables to answer this question (i.e. frequency, modulation & coding, Earth/Mars distance, atmospherics, antenna size, etc.)

What redundancies exist to handle packet loss when transmitting data from Mars to Earth:
I am unsure of the redundancies in place for the current Mars robotic missions. For future missions NASA is investigating a variety of technologies to include Disruption Tolerant Networking (DTN) that will handle the constrained Earth/Mars communications networks (see for more info: https://www.nasa.gov/content/dtn).

Why didn't the practice of the simulated ground and remote stations use the delay of the Moon instead, and wouldn't that be the ideal point to restart the human missions past the ISS?
When we began the BASALT analog project, we had not yet been redirected to return to the Moon. Regardless, things that we learn under Mars-like latencies are still very applicable to lunar conditions. When we started, it was assumed that there wasn't a functional way to connect the MSC to the astronauts that would enable Earth to help with intra-EVA tactical decision making through the latency. Our work has shown that this is actually very achievable. The Moon is an easier distance with regard to communication latency, but the lessons learned will still be transferable.

With VR pathways does it require the mission control team to remotely find the easiest path of travel (say, using orbiters) and then relay it to the EVA crew?
Fortunately, no. The VR pathways could be calculated on the Mars-side using existing topographic maps in our software Sextant. We pre-built suggested route maps in the MSC that were part of the Mission Brief sent to Mars each day, but the astronaut team did not have to rely on the MSC for updates or redirection.

How would emergency protocols change using this system, and in instances where the latency is too high how can the ground support help?
We did not consider emergency conditions as part of our simulations; if anything seemed like it might increase the risk to our field team, we immediately broke the simulation. Simulation breaks could be an hour-long stand down in order for a cloudburst to pass, or they could mean scrubbing the rest of the mission day. Safety was our number one priority. On a real human mission to Mars, though, the crew will need to be prepared to operate autonomously for any unexpected circumstance that would require action before a message could realistically return from Earth. This requires a lot of pre-planning for various contingencies in order to enable the crew to immediately work to resolve the issue and ensure safety.

When you run the HoloSEXTANT, is it hosted on the Mars or Earth side of the simulation? And is that software going to pose a bandwidth issue in mission application when astronauts on Mars are having to update that GIS system displaying their traverse when it has been changed by Mission Support on Earth?
It's hosted on the Mars side and ideally it updates in real time from information already on Mars so that space-to-Earth bandwidth is not required to make changes (esp during an EVA). Wrt Mars-to-Earth bandwidth, this is highly dependent on many factors such as compression algorithms (which will continue to improve as time goes on), surface and space assets, etc. and is largely unknown for future human Mars missions. Hence rather than make arbitrary assumptions about bandwidth, we focus on understanding what data products are required and when are they required and we also record detailed network analytics of everything we do during and between EVAs. Once bandwidth constraints, compression algorithms, assets, etc are better defined for future human class missions, we can then backfit our data to start defining what requirements we might need to put in place going forward.

What traditional geologic tools are still used by astronauts on EVAs – for example, are the EVA suits equipped to handle swinging rock hammers?
We have performed no geologic EVAs since Apollo, so none of our current EVA tools are "geological". However, a project has been recently initiated at Johnson Space Center to look at how we can use and improve upon the Apollo EVA tool set to enable scientific EVAs during the Artemis moon missions.

How many different roles beside the geo science lead and bio science lead are there?
Given that science within these broad categories can be very specific, there were many roles that fed decisions up into the geo and bio leads. Please see Payler et al. 2019 for more details WRT our BASALT roles. https://www.liebertpub.com/doi/10.1089/ast.2018.1846

What are opportunities for students to get involved in the program?
See earlier answer

How do you plan to adjust to changing scientific question as a mission progresses. For example field work for geochemical questions is different from the one for geophysics.
With the process in place to establish a Science Traceability Matrix, this type of adjusting can be done as the mission and even as an EVA progresses. If you have a deliberate and pre-planned way of making conducting democratic, vetted scientific decision-making, then this can be applied to dynamic situations, which exploration will always be no matter what planet we are working on.

Would the Minerva tool ever be made open source for collaboration?
It is already open source. Please see Marquez et al for more details.
https://www.liebertpub.com/doi/10.1089/ast.2018.1838

What's the benefits to work on modeling the science operation of space missions?
Of the hundreds of EVAs that NASA has carried out, only a few have been science-driven. We are entering a new age of space exploration, one that will be driven by scientific questions; if we're going to do that well, then it's critical that we enmesh the science, scientific operations, and basic exploration as soon as possible in order to learn how they inform one another.

Of the scientists working on the project, what was the deciding factor of who would go into the field, and who would stay behind in a supporting capacity?
One of our targets was balancing knowledge vs. expertise. All of our EV scientists were field-competent and established in their relevant field (at least a postdoc in volcanology, organic geochemistry, etc.), but we couldn't keep using them if they were perceived by members of the MSC as being "too expert", as that decreased the urgency felt by the MSC and undermined the simulation. Expert senior scientists held key positions in the MSC, reflecting the position of the true experts during anticipated human missions to Mars and the Moon.

How can you avoid the idea about having specialists at every turn in the process of the EVAs?
That's the beauty of having the big brains in the MSC and finding a way to have them provide tactical guidance during an EVA: you don't have to give up your need for specialists, you just need to place them within the science team on Earth. We need far more specialty knowledge than we could ever train the astronauts for, and we can only send a small crew, so it's important to find a way to actually scientifically support the mission from Earth while also enabling the astronauts to have a certain degree of operational autonomy, particularly as this pertains to conducting science and exploration.

Could we use VR/AR right now to create simulations of the martian surface in preparation for the future missions?
Absolutely! The folks at JPL have already created a version of this using images sent back by Curiosity:
https://mars.nasa.gov/news/8374/mars-virtual-reality-software-wins-nasa-award/?site=insight
The InSight VR of Mars is amazing. These same folks were part of our BASALT team and let us drive around Mars in the HoloLenses while they helped us to build our own version for our Hawaii 2017 field sites.

At what point in the field team's decision making does it become apparent that the time delay between the support center and the boots on the ground make the science too convoluted to perform?

We don’t know yet. When we picked 5 and 15 minute one-way latencies, we suspected that the scientists would strongly prefer working under the shorter delay. Surprisingly, the scientists in the BASALT MSC actually preferred the 15 minute latency because it changed how they perceived their timing and decision making. We did not test beyond the 15 minute one-way latency, so we didn’t find the threshold. Conceptually, though, we can anticipate that the too-long threshold may be dependent on the types of scientific tasks that the team is trying to carry out.

The VR and AR capabilities seem like an invaluable tool for those supporting the mission that can’t be in the field. However what level of prior mapping and scanning of an area are required for functional operation of these systems?

This is a great question and warrants a lot of detailed future work! We hope to someday conduct a dedicated precursor data study that specifically investigates what level of precursor data (e.g., data type [panochromatic imagery, lidar-derive topography, etc], data resolution, collection angle [e.g., overhead or oblique], and presentation mode) best serves both operational and scientific requirements of future Mars EVA. Much of this depends on the nature of the specific science objectives at hand, as well as various operational requirements (e.g. safety factors for the EVA crew).

Have there been any situations in the Basalt project where it was seen as more beneficial to have the command structure step back and not overly manage personnel in the field?

It’s really important to our operational design on BASALT that we *don’t* try to overly manage EV crew during a mission. The communication latency means that the more that the MSC tries to use the EV crew like a robotic asset, as opposed to treating them as insightful collaborators, the worse things tend to go. The MSC is always communicating from the past, so they have to operate reactively to the situation in the field. Kobs Nawotniak et al. (2019) talk about this in terms of communication between MSC and Mars:
https://www.liebertpub.com/doi/10.1089/ast.2018.1901